4. PERFORMANCE AND OPERATIONS OF THE DC-8-55 AIRPLANE WITH ACOUSTICALLY TREATED NACELLES

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SUMMARY

This paper describes the performance and operational characteristics of a model DC-8-55 airplane retrofitted with acoustically treated nacelles. The changes in airplane and engine performance due to the treated-nacelle installation were determined by analysis of the results of DC-8-55 flight tests and engine static tests.

The results of the analysis showed that the maximum range capability of the airplane with treated nacelles was improved by approximately 3.0 percent. Changes in take-off field length and block time were minimal. The initial cruise altitude capability was calculated to be reduced approximately 500 feet. The approved speed-altitude operating envelope and load-factor limitations for the airplane were unaffected by the installation of the treated nacelles.

Flight tests conducted by McDonnell Douglas Corporation and static tests conducted by the engine manufacturer showed that the treated nacelles did not affect compressor surge susceptibility. No surges were experienced during the flight-test program, or during static tests for power conditions from idle to take-off in simulated 90^{o} cross winds up to 35 knots. Static and inflight engine starting were also unaffected by the installation of the acoustically treated nacelles.

Engine compressor air-bleed requirements for inlet anti-icing would be increased by about 30 percent for a retrofit installation of treated nacelles on DC-8 airplanes with short fan ducts. However, this additional bleed will not result in a reduction in allowable take-off thrust at sea level. At 8000 feet, the thrust loss at take-off power due to inlet anti-icing would be approximately 0.6 percent.

The serviceability of various acoustical materials exposed to the environment of actual airline operation is currently under investigation. Twelve test samples of fiber metal installed in the fan-discharge ducts of Western Airlines 720B and American Airlines 707 airplanes have accumulated up to 1200 hours of test time. No cleaning or repair of the samples has been required in this time.

INTRODUCTION

Ground static and flight tests were conducted to evaluate the aerodynamic performance and operational characteristics of a short-duct DC-8 airplane equipped with acoustically treated nacelles. The portion of the test program relating to aerodynamic performance and operational characteristics is the subject of this paper. The results of the flyover noise tests are presented in paper no. 5 by Marsh. The aerodynamic performance reported herein was subsequently used in a study of the economic effects of an assumed treated-nacelle retrofit program for all models of the DC-8 series 50 airplanes and the DC-8-61.

The nacelle design selected for the test program included acoustically treated inlet and fan-discharge ducts. The inlet had acoustical treatment on the surface of the inlet duct and center body and on both surfaces of a concentric ring vane. The fan-discharge ducts were twice as long (48 inches) as ducts in current production and had acoustical treatment applied to the walls of the ducts and the four duct splitters. A more detailed description of the treated nacelle is included in paper no. 3 by Pendley.

The flight-test airplane was a DC-8-55 airplane furnished by Seaboard World Airlines. The performance and operational effects shown herein were determined for a passenger version of the airplane.

ENGINE AND AIRPLANE PERFORMANCE

The McDonnell Douglas performance test program consisted of ground static tests and flight tests. The structural integrity of the treated nacelle and the compatibility of the nacelle with the engine were evaluated from the results of the static tests. The effect of the treated nacelles on static engine performance and on thrust at rated engine power was also determined. The results of the flight-test program were used to determine airplane specific range. The results of both the static-test and flight-test programs were used to calculate the effect of the treated nacelles on airplane take-off, climb, and payload-range performance.

Static tests were conducted by Pratt & Whitney Aircraft (P&WA) to evaluate the effect of the acoustical treatment on engine operation, thrust ratings, and compressor surge susceptibility in simulated cross winds.

Static Tests

An existing nacelle and a treated nacelle were tested statically by McDonnell Douglas with the same JT3D engine to determine the change in engine performance due to the modification. Figure 1 shows a treated nacelle on the calibrated test stand located at

Edwards Air Force Base. The engine controls and data readout system were located in a nearby test-control center. A nonmetric afterbody shield isolated the fan jet from the gas-generator cowling and prevented the scrubbing drag caused by the fan-discharge flow from being included in the thrust measurement. The test-stand thrust results therefore included only the effects of internal flow on engine performance. The change in scrubbing drag due to the more rearward location of the fan-discharge nozzles was calculated by analysis to be 0.4 percent at take-off power.

Figure 2 shows that the change in thrust caused by the treated nacelle at indicated engine pressure ratios (EPR) corresponding to high engine powers is less than 1 percent at constant values of EPR. The results also showed less than 0.5 percent change in fuel flow and rotor speeds at constant EPR.

A treated nacelle was tested by P&WA at their facility in East Hartford, Connecticut. Data obtained in these tests were used to determine the thrust ratings that would permit operation of the treated nacelle with existing engine warranties. The following average thrust reductions, relative to the performance of the existing installation, resulted from the revised thrust ratings:

Rated take-off thrust	2.5%
Rated maximum climb thrust	2.9%
Rated maximum cruise thrust	3.1%

Flight Tests

The airplane flight-test program was conducted first with the existing nacelles. The test schedule was then repeated with the treated nacelles installed. The same engines were used for both tests.

The airplane performance test results were used to evaluate the airplane range factor in nautical miles at three values of referred airplane gross weight (W/δ) over a range of cruise Mach numbers. Figure 3 shows the results of the range-factor evaluation for the lowest and highest values of W/δ (where W represents airplane weight in pounds and δ is the ratio of ambient pressure at altitude to sea-level standard pressure). Range factor is defined as the product of airspeed in knots and airplane referred weight in pounds divided by the rate of fuel flow in pounds per hour. An improvement in range factor varying from approximately 1.3 percent at high values of gross weight to 4.4 percent at low values was indicated at Mach number 0.82 for the airplane with treated nacelles. The average improvement at that Mach number was 3.0 percent for the gross weights tested. At higher Mach numbers and at high values of airplane gross weight, the treated-nacelle installation caused a decrease in range factor. However, an airplane with high gross weight is not normally operated at high Mach numbers because this combination is relatively uneconomical.

The flight-test program was limited to the determination of airplane range factor. Test instrumentation and procedures did not provide for the separate measurement of thrust. The reason for the range-factor changes are not, therefore, directly indicated. On the basis of the improved range factor, however, it was inferred that the drag of the treated airplane was approximately 3 percent less than that of the existing airplane. The drag reduction was probably related to the change in the flow field in the region of the wing, pylon, and nacelle caused by the lengthened fan-discharge duct.

Airplane Performance

Figure 4 shows the effect of the treated nacelles on specific range for three values of airplane gross weight at an altitude of 30 000 feet. Specific range was calculated by dividing the range factor by the airplane weight. Specific range is a measure of the range flown per pound of fuel burned. The effect of the previously mentioned 3.1 percent reduction in maximum cruise thrust on maximum cruise Mach number is also indicated in figure 4 for standard conditions and standard plus 10^{o} C. The reduction in rated cruise thrust would not preclude operating the airplane at Mach numbers typically used at these temperatures, even at high airplane weights.

The effect of the treated nacelles on the payload-range characteristics is shown in figure 5. The improvement in specific range shown in figure 4 is reflected in figure 5 by the improvement in range, approximately 3 percent, shown for operation at the 325 000-pound maximum take-off gross weight. The performance is shown for a reference payload consisting of 135 passengers, their baggage, and 2500 pounds of cargo. Figure 5 also shows that the weight-limited payload is the same for both the treated and existing airplanes. Because the 332-pound increase in airplane operating weight empty described by Pendley in paper no. 3 is small, and because the added weight acts as a relieving wing bending moment, no change in weight-limited payload was necessary.

Figure 6 shows the effect of the performance changes on take-off field length requirements. Required field lengths corresponding to ranges less than 2500 nautical miles are slightly longer for the treated airplane than for the existing airplane, whereas field lengths for longer ranges are slightly shorter. For ranges less than 2500 nautical miles, the improvement in specific range (fig. 4) and the resulting reduction in fuel load for the treated airplane were not sufficient to compensate for the reduction in take-off thrust. The take-off field length required for short ranges was therefore greater for the treated airplane. At long ranges, the reduction in fuel load for the treated airplane more than compensated for the reduction in take-off thrust, and the required take-off field length was therefore less.

Thrust for calculating airplane climb performance was based on the results of the ground static tests which showed that the treated nacelle would cause a reduction in rated

climb thrust of 2.9 percent. This reduction is essentially equal to the 3-percent inferred average reduction in airplane drag. Since the lowest test Mach number during the flight-test program was 0.65, the effect of the treated nacelles on airplane range factor, and therefore on inferred drag, at Mach numbers lower than 0.65 was not known. During typical climb operations, a Mach number of 0.65 is attained at approximately 20 000 feet. Therefore, at altitudes above 20 000 feet, the reduction in rated climb thrust would approximately equal the average reduction in inferred drag, and the rate of climb would be unaffected. At lower altitudes, where the beneficial drag reduction may not be present, but where the rate of climb is high, the effect of the thrust reduction on climb performance would be small. A small increase in total time to climb to cruising altitude would be expected.

Calculations indicated that the treated-nacelle installation will affect the maximum initial cruise altitude capability. The maximum initial cruise altitude of the DC-8-55 for all actual gross weights occurs at a W/δ of 1,100,000 pounds. The cruise data at this W/δ and a Mach number of 0.82 show an apparent drag reduction of 1.2 percent. This reduction in drag is more than offset by the 3-percent loss in thrust due to the reduction in rated maximum cruise EPR. The resultant loss of 1.8 percent in the thrust-minus-drag margin is estimated to produce a 500-foot decrement in maximum initial cruise altitude. This decrement would not affect range capability at long-range cruise and would cause no more than a 5-mile range reduction for cruise at a Mach number of 0.82.

As previously noted, the cruise Mach number is unchanged by the treated-nacelle installation. It was estimated that the increase in block time would be less than 1 minute, for a range of 850 nautical miles, because of the small increase in time to climb.

The performance of the treated airplane indicated that the approved altitude-speed envelope for the DC-8-55 would be unchanged by the installation of the treated nacelles. Flutter and strength analyses showed that the load-factor limitations would be unaffected.

OPERATIONS

Engine Operation

The static tests of the treated nacelle conducted by P&WA indicated that the nacelle modification did not cause an increase in compressor surge susceptibility in simulated 35-knot cross winds. No compressor surges occurred during the flight-test program.

Both the static-test and flight-test programs showed that the engine starting envelope would be unaffected by the treated nacelle.

Ice Protection

The design of the inlet included provisions for anti-icing the ring vane and the supporting struts by the use of compressor bleed air (as in the existing cowl system). The bleed airflow required was calculated to be 30 percent more than the inlet anti-icing air bleed required for the existing nacelle.

The engine may be overboosted at take-off power to compensate for the thrust decrement caused by bleeding up to 1 percent of engine airflow for inlet anti-icing. The air bleed required to anti-ice the inlet of the treated nacelle was less than 1 percent of engine airflow at sea level. Therefore, no additional thrust penalty due to inlet anti-icing would be incurred during take-off at sea level. At 8000 feet, the additional thrust penalty would be approximately 0.6 percent.

The results of the operational considerations on performance are summarized as follows:

Altitude-speed envelope	No change
Load-factor limitations	No change
Compressor surge susceptibility	No change
Engine starting capability (static and inflight)	No change
Take-off thrust change due to inlet anti-icing at –	
Sea level	No change
8000 ft	0.6% less

Maintenance

Estimates of the maintenance costs of acoustically treated ducts are uncertain at this time because of the limited service experience with such materials. Specimens of acoustical material are being exposed to the nacelle environment in routine service in order to determine the useful life of such materials, the manner in which deterioration occurs, the rate at which porous materials become clogged, and the effectiveness of alternative methods for cleaning contaminated specimens.

Several different kinds of materials are presently in service in the fan-discharge ducts of Boeing 707 and 720B and Douglas DC-8-63 airplanes.

Figure 7 illustrates the components of an installation of two specimens in existing screw-mounted panels located in the fan-discharge ducts of Boeing 720B nacelles. These specimens, 8 inches in diameter, are constructed of fiber metal bonded to fiber-glass honeycomb. The specimen in the right side of the panel is shown in position just prior to the installation of its mounting screws. In the left side of the panel is a specimen with the acoustical material removed.

All specimens are assembled in the receptacle shown on the upper right. The receptacle has large perforations to permit flow-resistance tests of the specimens when they are removed from time to time for inspection. Impervious cover plates (one of which is shown in the upper middle of fig. 7) are used to seal the perforations when the specimens are installed.

Twelve specimens have been introduced into aircraft operated by American Airlines and by Western Airlines. As of September 1969, these specimens have accumulated a total exposure time of 8440 hours. Of the specimens that have been returned for inspection, the high-time specimen has experienced 1166 hours of flight exposure. Two specimens have experienced minor foreign-object damage which did not require repair, and all specimens have shown evidence of oil and dust contamination. However, the contamination was not sufficient to affect the flow resistance measurably and, therefore, cleaning was not required.

The bonded construction described above was selected in 1967 for the acoustical materials used in the present program. Since that time, studies of other materials assembled in other ways have been continued, and specimens of the newer materials will also be tested in the Boeing 720B installation. Specimens of integrally woven fiber-glass fabrics, impregnated with polyimide resins, will soon be introduced.

In a second program, another type of acoustical material has been incorporated into two removable sections of the long fan-discharge ducts of a DC-8-63 airplane (fig. 8) operated by Flying Tigers Airlines. This material was installed throughout the internal surfaces of the duct section shown. This installation consists of an adhesively bonded aluminum sandwich. The honeycomb core was bonded between a perforated facing sheet and a solid backing sheet. Four circular receptacles were incorporated into the basic material installation to permit periodic removals and inspection of small specimens. The duct sections were recently introduced into service, and they have accumulated approximately 200 hours exposure at this time. No problems with the duct sections have been reported by the operator, and the results of the first laboratory inspection of the small specimens will soon be available.

CONCLUDING REMARKS

The modification of the nacelles of DC-8 aircraft having short fan-discharge ducts required to install acoustical treatment results in a significant improvement in airplane payload-range capability and essentially no change in take-off field length and block time. Initial cruise altitude capability would be reduced approximately 500 feet.

The approved airplane performance envelopes and load-factor limitations are unchanged by the modification.

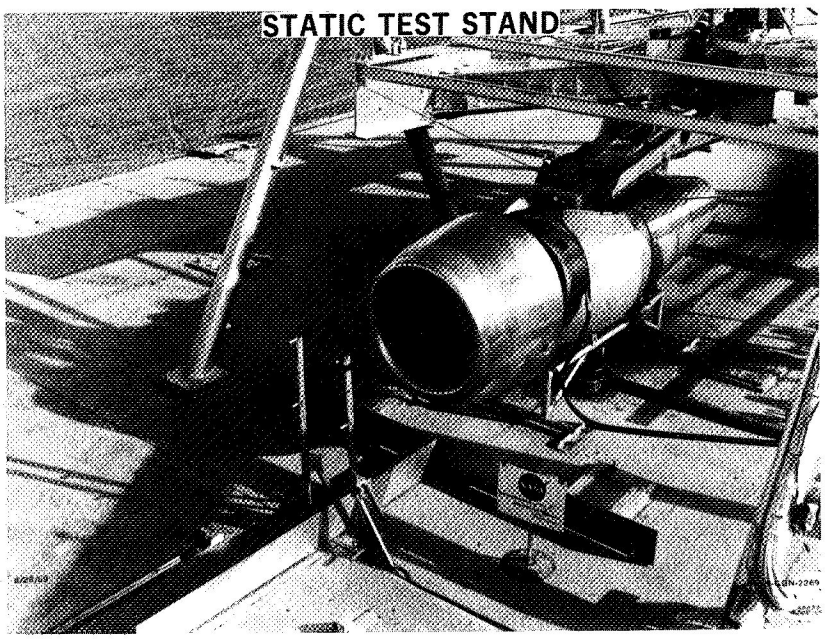

Figure 1

JT3D STATIC-TEST RESULTS

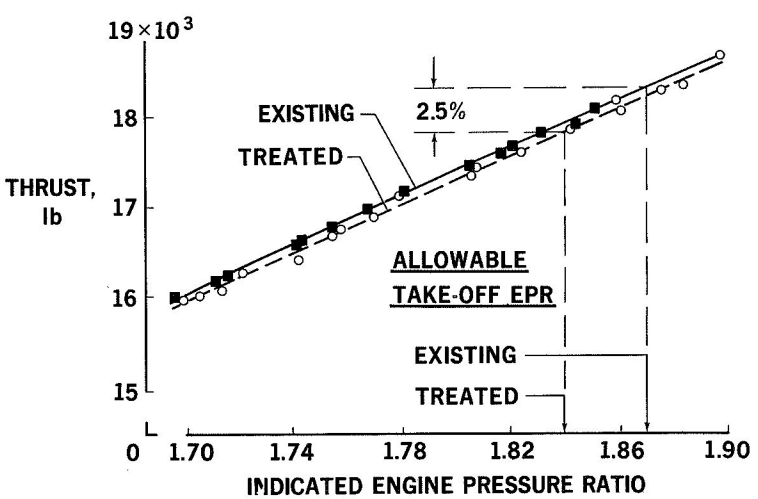

Figure 2

MEASURED FLIGHT-TEST RESULTS
DC-8-55

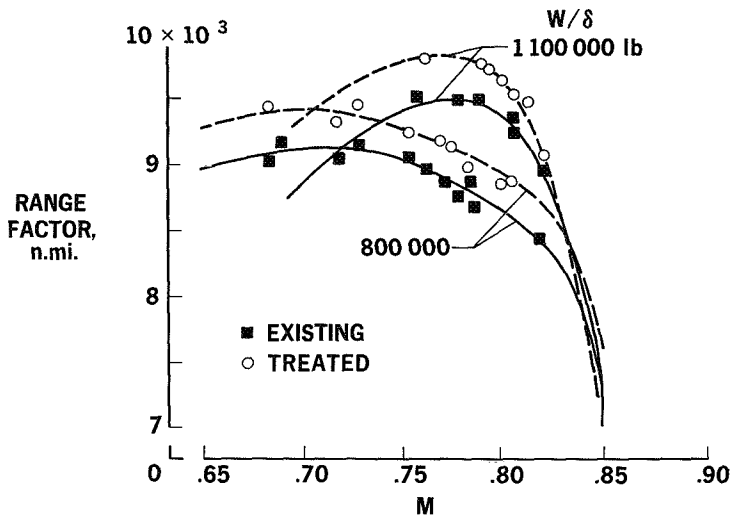

Figure 3

SPECIFIC RANGE
ALTITUDE = 30 000 ft; DC-8-55

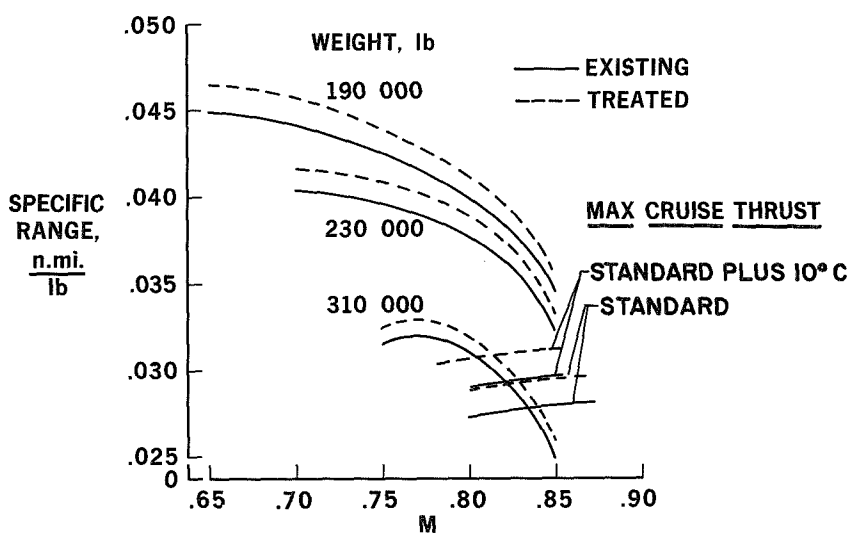

Figure 4

PAYLOAD-RANGE CHARACTERISTICS
INTERNATIONAL OPERATING RULES; STANDARD DAY
DC-8-55

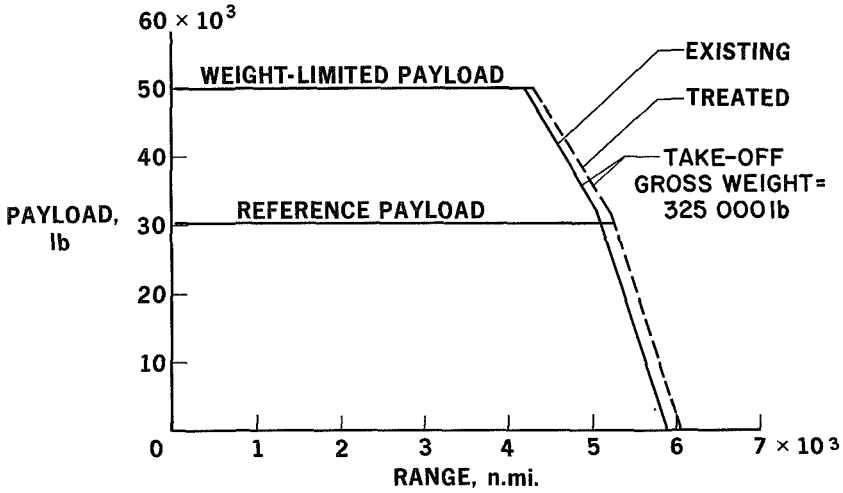

Figure 5

CALCULATED FIELD LENGTH REQUIREMENTS
STANDARD DAY; SEA LEVEL
REFERENCE PAYLOAD; DC-8-55

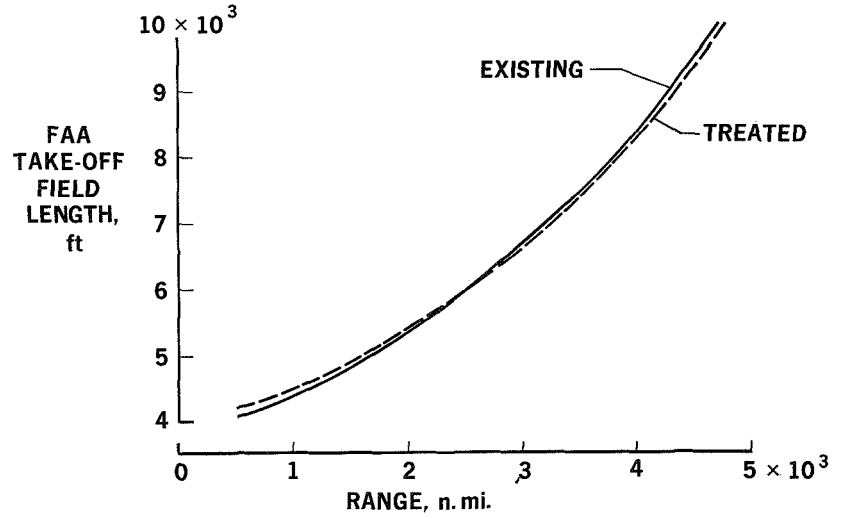

Figure 6

SERVICE-TEST SPECIMEN FOR SHORT-DUCT INSTALLATION
BOEING 720B

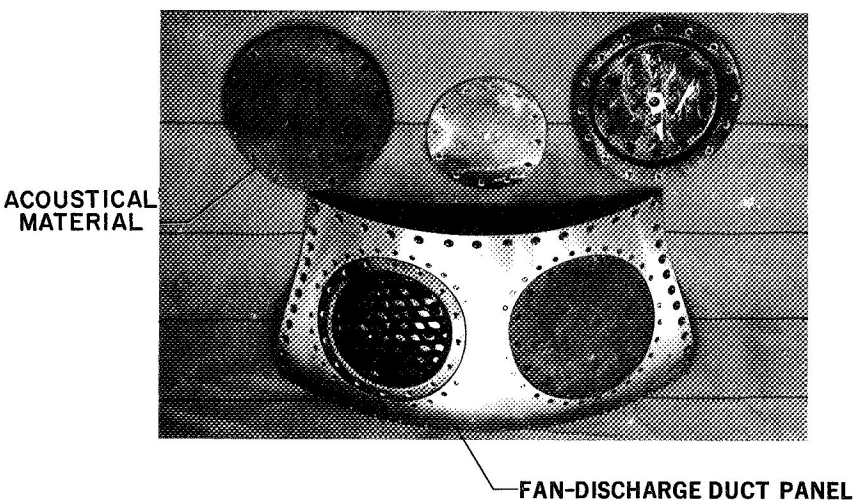

Figure 7

SERVICE-TEST SPECIMEN FOR LONG-DUCT INSTALLATION
DC-8-63

Figure 8